

Groundwater Potential Assessment Using Geoelectrical Data: A Case Study Of Phuket Island, Thailand

Avirut Puttiwongrak (■ puttiwongrak.a@gmail.com)

Asian Institute of Technology https://orcid.org/0000-0002-9840-2854

Ratha Men

Prince of Songkla University Phuket Campus

Thongchai Suteerasak

Prince of Songkla University Phuket Campus

Sakanann Vann

Prince of Songkla University Phuket Campus

Research Letter

Keywords: Vertical Electrical Sounding, Groundwater potential, Dar Zarrouk parameters, Geoelectrical data

Posted Date: September 18th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-77347/v1

License: © ① This work is licensed under a Creative Commons Attribution 4.0 International License.

Read Full License

GROUNDWATER POTENTIAL ASSESSMENT USING GEOELECTRICAL DATA: A CASE STUDY OF PHUKET ISLAND, THAILAND Avirut Puttiwongrak^{1*}, Ratha Men², Thongchai Suteerasak² and Sakanann Vann^{2,3} Geotechnical and Earth Resources Engineering, Asian Institute of Technology, PO BOX 4, Klong Luang, Pathumthani, 12120, Thailand Faculty of Technology and Environment, Prince of Songkla University, Phuket Campus, 80 Moo1, Vichit-Songkram Rd., Kathu District, Phuket 83120, Thailand

³Andaman Environment and Natural Disaster research center (ANED), Prince of Songkla University, Phuket

Campus, 80 Moo1, Vichit-Songkram Rd., Kathu District, Phuket 83120, Thailand

*E-mail: puttiwongrak.a@gmail.com

Abstract: Groundwater is the dominant source of water supply on Phuket island, Thailand. The water demand on Phuket has been increasing due to rapid urbanization and population growth. A scarcity of freshwater and over-extraction of groundwater may shortly become severe problems for Phuket. Geoelectrical data obtained by Vertical Electric Sounding (VES) were employed in this study to estimate the Dar Zarrouk parameters of the study area. Twenty-four VES stations were set up using Schlumberger configuration with a 1.0 m minimum spacing. The lithology layers from 24 unpublished borehole data indicating each subsurface layer were validated with the resistivity data obtained from VES. The geoelectric profiles gave a maximum of three layers with varying resistivities and thicknesses across each VES station. Two parameters (longitudinal conductance and transverse resistance) of the Dar Zarrouk model were calculated from VES data to generate the thematic maps in a GIS environment, thus the groundwater potential in Phuket Island was represented as a single map by using the weighted overlay technique in ArcGIS,

- based on both longitudinal conductance and transverse resistance. The groundwater potentials were classified into three potential levels (low, medium, and high). The results reveal that the highest groundwater potential areas are isolated and in specific locations, while the majority of area has medium level groundwater potential. Finally, the low potential zones are in the flank and the top parts of the study area.
- **Keywords:** Vertical Electrical Sounding, Groundwater potential, Dar Zarrouk parameters,

1. Introduction

Geoelectrical data.

During the last decade, Phuket Island has been among the most favourite places for tourists visiting Thailand, with growth by around 100,000 visitors/year annually (ISET 2014). Indeed, Phuket island has experienced massive urbanization and now relies heavily on the tourism business. The water supply has remained inadequate with respect to the water demand on Phuket, which has dramatically risen due to increased population and growth of tourism. A lack of surface water sources, especially in the summer season, leads to groundwater serving as the crucial resource. Due to the population explosion and the tourism development, the demand for water on Phuket is expected to grow by approximately 180,000 m³/day by 2025 (ISET 2014), and groundwater is the main source exploited on Phuket at present. Groundwater has become the key water resource and plays an important role to tourism and to households. Therefore, an assessment of groundwater potential on Phuket island is important for the future water resource use scenarios.

Groundwater exploration on Phuket is needed in order to meet the growing demand for water. Several thousand wells have been produced in the area. Many abortive wells were sunk and abandoned due to the failure of an initial proper investigation, thus proper precautions are

suggested to reduce the risk of wasting money on sinking abortive wells (Ezeh and Ugwu 2010). Consequently, a groundwater potential map is needed to provide quantitative groundwater conditions, showing the proper sites for drilling groundwater wells. Also, techniques of groundwater exploration have been the key for studying groundwater potential (Zaidi and Kassem 2012). The geophysical method has played an important role in groundwater exploration for many years because of its reliability, ease of getting subsurface information, and nondestructive character. The electrical resistivity survey using Vertical Electrical Sounding (VES) method is the most popular geophysical technique for the assessment of groundwater potential (Ndatuwong and Yadav 2015). In the VES method, four electrodes including two current electrodes (A and B electrodes) and two potential electrodes (M and N electrodes) are used for the resistivity measurement of the subsurface. The electrical current is injected into the subsurface to measure the resistivity, providing depth of occurrence of groundwater and the thickness of the aquifer system, based on the contrast in resistivity values (Ali et al. 2015; Devi et al. 2001). The resistivity of natural water and sediment without clay layers varies in the range from 1 to over 1,000 Ohm.m depending on ionic concentrations and dissolved solids (Maury and Balaji 2014). Coker (2012) conducted successfully VES to delineate potential groundwater aquifers in Akobo area, Ibadan, South-Western Nigeria, revealing both weathered and fractured horizons of the productive water-bearing zones representing the groundwater potential aquifers. Similarly, Gowd (2004) employed the VES method to correlate with the existing lithology and the weathered and fractured zones in both shale and limestone as the productive water-bearing zones having fresh groundwater potential. The estimation of some secondary parameters from resistivity data to assess the groundwater potential relies on a fundamental relationship between hydraulic properties and resistivity (Hasan et al. 2018; Anbazhagan and Jothibasu 2016;

50

51

52

53

54

55

56

57

58

59

60

61

62

63

64

65

66

67

68

69

70

71

Ndatuwong and Yadav 2015). In addition, the integration of secondary aquifer parameters calculated from resistivity data was mapped as a thematic map of groundwater potential zones using the Geo-Informatic System (GIS), which is an appropriate platform for the analysis of diverse datasets from groundwater mapping (Anbazhagan and Jothibasu 2016). The integration of the GIS environment and VES method has been successful in delineating the groundwater potential map (Anbazhagan and Jothibasu 2016; Ojo et al. 2016; Ndatuwong and Yadav 2015; Ali et al. 2015).

73

74

75

76

77

78

79

80

81

82

83

84

85

86

87

88

89

90

91

92

93

94

95

On Phuket island, very few studies related to groundwater potential prospects have been done; therefore, a better knowledge of the aquifer formation and evaluation in this area is needed to understand the spatial distribution of groundwater. Additionally, the occurrence of groundwater in this area exposing basement complex rocks in fractures and weathered zones is also not well understood, although there are a number of studies related to hard-rock groundwater (Tesfaldet et al. 2020; Tesfaldet and Puttiwongrak 2019; Putiwongrak et al. 2018; Gupta et al. 2000). Assessments and evaluations related to the groundwater potential on Phuket island were carried out by Charoenpong et al. (2012) using groundwater specific capacity (SPC) with an optimal interpolation technique to create a groundwater potential map. A constraint of their study was that the data points were acquired based on the available producing wells, hence may have not been representative of the entire island, leading to significant spatial errors. The aim of this research was to attempt to delineate the groundwater potential zones of Phuket using the aquifer properties obtained from the interpretation and calculation of VES data with the integration of GIS techniques. Furthermore, this study acts as a guide for future groundwater exploration and drilling in the study area, and the database obtained from this study can improve the success rate of future groundwater exploitation.

2. Methodology

2.1 Study area description

Phuket island is situated in the southern peninsular part of Thailand. It lies within latitudes 70° 58'30"N and 70° 51'50" N and longitudes 98°15'10"E and 98° 21'50" E and is bordered by the Andaman Sea, covering an area of approximately 543 km² as shown in Fig. 1. The study area

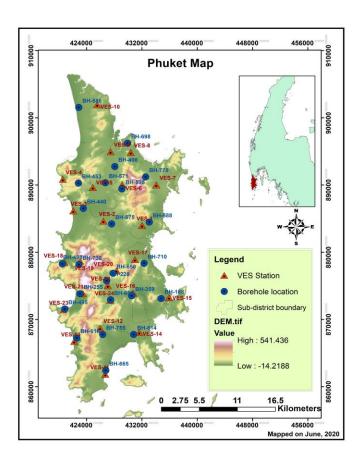


Fig 1. Map of study area showing VES stations and borehole locations

is rural with growth potential for urbanization and tourism. Geologically, the study area has a diverse landscape including mountainous topography, alluvial plain, and coastal tracts. Phuket Island is a younger sequence of basement rocks that originated during the Oligocene to late Cretaceous geological ages (Maury and Balaji, 2014). The rocks are mostly granite and

extensively weathered by tectonic processes that provide good potential for groundwater. Hydrogeologically, the study area falls within the weathered and fractured units of hard rock environment that can hold the groundwater, and the water-bearing capacity is increased by weathering and fracturing. The rainfall pattern in the study area is certain and rainy for most of the year, thus the climate usually alternates with the dry and rainy seasons only. Rainfall is relatively high in the monsoon period (June - September), and the highest rainfall is in August when the water level become shallower than 10 mbgl (meter below ground level) in some places.

2.2 Geoelectrical survey using Vertical Electric Sounding (VES) method

A geoelectrical survey using VES method was conducted at 24 stations as shown in Fig. 1.VES technique is used to measure resistivity based on the response of the subsurface to the flow of an electrical current (Amadi et al. 2011). The subsurface resistivity is a function of the electrical current, the potential difference, and the geometry of the electrode array. A resistivity measurement is dependent on water saturation and pore space connectivity of the subsurface. In addition, the Global Positioning System (GPS) was used for measuring the coordinates of every VES station as geo-referenced location. The VESs were carried out by employing a Schlumberger configuration using the SuperSting R2 resistivity meter (AGI 2016), and the measurement was set by a half-current electrode spacing (AB/2) range from 5 to 200 m. The Schlumberger configuration was selected in this study because accurate lateral variation of resistivity is measured from the duplication of readings with the same values of AB/2 and different values of MN/2. The current electrodes (A-B distance) were extended in successive steps for further measurements, while the potential electrodes (M-N distance) were kept constant at any measurement until finishing the desired configuration.

In addition, a quantitative interpretation of the resistivity data was considered by the variation in the apparent resistivity for each electrode spacing. Based on this concept, layer resistivity and thickness estimates were obtained by using the EarthImager 1-D software (AGI 2014) to interpret all the obtained data sets. Apparent resistivity and AB/2 value relationships were plotted by the software and qualitative interpretation of the subsurface resistivity distribution was performed by the computer iteration technique, which successfully reduced the interpretation errors. The layer (true) resistivities and thicknesses were obtained using a partial curve matching technique to produce the resistivity-thickness model at least Root-Mean-Square (RMS) error between measured and calculated resistivity values. Furthermore, the models were optimized in order to eliminate the non-predictive bias interpretation by correlating with the lithology information from groundwater borehole data. The lithology information of the borehole data was based on earlier work in the study area (Puttiwongrak et al. 2019), and all model results were in a good agreement with the geological formations of existing boreholes.

2.3 Aquifer parameter calculations

In general, the hydraulic and electrical conductivities of the sediment deposition are greater in the horizontal direction than the vertical direction (Ndatuwong and Yadav 2015). The first order geoelectric parameters obtained from the iteration of 1-D inversion were used to calculate second-order geoelectric parameters or the Dar Zarrouck parameters (Mailet 1974). The second-order parameters used in this study include total longitudinal conductance (S) and total transverse resistance (T). The variation of S and T in hard rock indicates the predominance of resistive and conductive zones implying the groundwater potential in the formation above the bedrock. The ratio of the thickness and resistivity of a layer defined the longitudinal conductance, while the transverse resistance is the product of the thickness and resistivity of a

layer. Both *S* (mho) and *T* (Ohm-m²) were calculated using the equations (1) and (2) respectively from Mailet (1974).

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} \tag{1}$$

$$T = \sum_{i=1}^{n} h_i \rho_i \tag{2}$$

Here h (m) is the thickness of the layer obtained from VES in each station, ρ (ohm-m) is the electrical resistivity of the layer obtained from VES in each station and n is the number of layers in the geoelectric profiles.

2.4 Geographic Information System (GIS) techniques

The parameters calculated in section 2.3 were imported in the form of point data for each station with geo-references to the GIS environment, and ArcGIS software was operated for data generation and spatial analysis with a projection to the geographic coordinate system of the World Geodetic System 1984 (WGS 1984) datum. The spatial analysis extension of ArcGIS was used to produce the thematic maps of S and T as the base maps, and both thematic maps were integrated using a weighted overlay method to generate groundwater potential mapping. During the weighted overlay analysis, the ranking was given for each parameter of each thematic map, and the weights were assigned according to the influence of the different parameters (Nagarajan and Singh 2009; Kura et al. 2014). Areas of low S are associated with high T in the groundwater potential map and are indications of good potential in the zone (Ndatuwong and Yadav 2015).

3. Results and discussion

3.1 Interpretation of 1-D Vertical Electric Sounding

Twenty-four VESs, randomly distributed, were carried out over the entire Phuket island at the locations shown in Fig. 1. The measured resistivity in the field survey, called the apparent resistivity (or isoresistivity), needed to be derived by the iterative inversion method to obtain the true resistivity of the subsurface materials. Then, the VES data were interpreted by the curve matching technique with help of computer software called 1D EarthImager. The interpreted results provided the distribution of the resistivities with layer thickness, giving a clear picture of the subsurface geology of the study area. From interpretation of the VES curves, three main subsurface units were identified within the study area, including topsoil, weathered basement, and fresh bedrock. The low resistivity zone (14 – 100 Ohm-m) is typically an aquifer layer ranging from 7 to 40 mbgl, which were interpreted as the weathered basement in the second layer of all geological units. The topsoil layer varies in resistivity between 50 and 200 ohm-m and the thickness ranges from 4 to 20 mbgl. Lastly, the fresh bedrock is characterized by high resistivity that exceeds 300 ohm-m in all locations of the study area. To validate the accuracy of

the VES interpretations, the interpretation curves were correlated in close proximity of existing borehole data from the field surveys (Fig. 1). The correlations show good agreement in the lithology between VES interpretations and borehole information, as exemplified by an example of VES-18 and borehole BH-498 (Fig. 2). In addition, it is interesting to note that the VES interpretations are also in accordance with the geological profiles proposed by Giao et al. (2008). The measurement results from 24 VES stations were interpreted in correlation with borehole lithology as shown in Table 1.

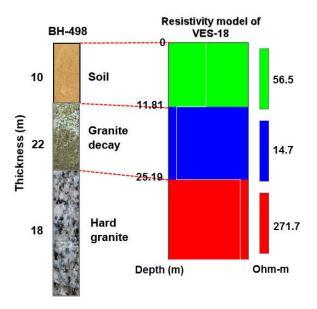


Fig 2. Correlation of layered resistivity model with borehole lithology

Table 1. Summary of geoelectric and borehole profiles

VES Station	VES Coordinates		Borehole	BH Coordinates		Correlation of geo-electric and bore hole profile								
						1st Layer			2nd Layer			3rd layer		
	UTM-X	UTM-Y	ID	UTM-X	UTM-Y	h ₁ (m)	ρ ₁ (Ohm-m)	Soil types	h_2	ρ_2	Soil types	h_3	ρ_3	Soil types
VES-1	432031	883958	BH-588	433067	884493	7.68	50.0	Soil shale	31.6	30	Granite decay	N/A	100	Granite
VES-2	426441	884623	BH-575	427639	884215	20.19	91.9	Soil shale	41.46	27.5	Granite decay	N/A	111.5	Granite
VES-3	422078	886148	BH-440	423548	886533	6.22	84.2	Soil	20.12	29.3	Clay	N/A	100.3	Clayey rock
VES-4	420563	890834	BH-453	422834	890284	6.73	81.9	Soil shale	20.87	40.3	Granite decay	N/A	114.2	Granite
VES-5	424905	889617	BH-571	426722	890331	10.68	140.8	Soil	12.79	100.2	Weathered rock	N/A	303.2	Granite
VES-6	429157	890042	BH-595	429118	889424	16.93	128.4	Soil shale	39.02	100.4	Granite decay	N/A	247.9	Granite
VES-7	434078	890005	BH-770	432550	891212	8.83	145.5	Soil shale	15.62	101.3	Granite decay	N/A	240.9	Granite
VES-8	430386	894824	BH-698	429940	896221	4.93	57.5	Soil shale	23	19.9	Granite decay	N/A	98.5	Granite
VES-9	427470	894941	BH-496	428092	892751	5.98	80.6	Soil	33.39	44.2	Clay	N/A	193.7	Weathered rock
VES-10	425533	901940	BH-586	422880	901549	5.32	63.1	Soil	14.56	53.5	Clay	17.48	23.5	Clayey sand
VES-11	426708	861838	BH-665	426788	862424	4.04	144.9	Soil	6.84	45.5	Sticky soil	11.86	136.6	Clayey sand
VES-12	425957	868701	BH-755	426332	867773	12.67	92.3	Soil	13.75	52.8	Clayey sand	12.26	49.4	Weathered rock
VES-13	422216	866712	BH-616	422602	867255	29.15	139.4	Soil shale	15.13	48.7	Granite decay	N/A	342.4	Hard granite
VES-14	431614	868061	BH-614	430811	867770	19.37	138.1	Soil	21.14	53.3	Weathered rock	N/A	374.2	Granite
VES-15	435927	873251	BH-168	434783	873115	14.49	2.5	stone decay	N/A	221.3	Hard granite	N/A	N/A	N/A
VES-16	430728	873934	BH-359	430529	873529	12.12	172.6	Soil	N/A	100.4	Granite decay	N/A	N/A	N/A
VES-17	430982	878905	BH-710	432316	878339	5.87	96.0	Soil	28.99	43.5	Weathered rock	N/A	191.1	Granite
VES-18	420825	878440	BH-498	420506	878277	11.81	56.5	Soil	13.38	14.7	Granite decay	N/A	271.7	Hard granite
VES-19	423061	878654	BH-738	422900	878142	20.33	114.5	Soil shale	N/A	200.2	Granite decay	N/A	N/A	N/A
VES-20	428337	877270	BH-650	427834	876869	6.75	160.1	Benthic	5.2	59.7	Cleyey sand	13.81	25.3	Weathered rock
VES-21	423468	873838	BH-255	423062	873836	10.13	61.8	Clay	8.01	21.8	Weathered rock	N/A	195.5	Granite
VES-22	427071	875008	BH-220	426916	875750	27.23	134.1	Benthic	7.19	100.5	Granite decay	N/A	214.5	Granite
VES-23	420668	871425	BH-495	420860	871562	10.41	107.5	Soil	39.81	15.6	Weathered granite	N/A	181.5	Hard granite
VES-24	427417	872842	BH-682	427479	872932	12.83	210.3	Soil	N/A	100.4	Weathered granite	N/A	N/A	N/A

3.2 Thematic maps of longitudinal conductance and transverse resistance

Dar-Zarrouk parameters, as described in Table 2, are useful for differentiating aquifer characterizations towards an assessment of the groundwater potential. In this study, the Dar-

Table 2. Transverse resistance and longitudinal conductance in the study area

VES Station	Borehole ID	Transverse resistance T (Ohm-m ²)	Longitudinal conductance S (mho)
VES-1	BH-588	1332.00	1.21
VES-2	BH-575	2995.61	1.73
VES-3	BH-440	1113.24	0.76
VES-4	BH-453	1392.25	0.60
VES-5	BH-571	2785.30	0.20
VES-6	BH-595	6091.42	0.52
VES-7	BH-770	2867.07	0.21
VES-8	BH-698	741.18	1.24
VES-9	BH-496	1957.83	0.83
VES-10	BH-586	1525.43	1.10
VES-11	BH-665	3146.78	2.61
VES-12	BH-755	2501.09	0.65
VES-13	BH-616	4800.34	0.52
VES-14	BH-614	3801.76	0.54
VES-15	BH-168	36.23	5.80
VES-16	BH-359	2091.91	0.07
VES-17	BH-710	1824.59	0.73
VES-18	BH-498	863.95	1.12
VES-19	BH-738	2327.79	0.18
VES-20	BH-650	1391.12	0.68
VES-21	BH-255	800.65	0.53
VES-22	BH-220	4374.14	0.27
VES-23	BH-495	1740.11	2.65
VES-24	BH-682	2698.15	0.06

Zarrouk parameters longitudinal conductance and transverse resistance were calculated from the geoelectric parameters obtained from VES interpretations, as shown in Eqs. 1 and 2, respectively. The transverse resistance is usually associated with the transmissivity of the aquifer

characterizing permeability to fluid, while the ratio of different layers to respective resistivity is known as the longitudinal conductance. Hence, the high transverse resistance indicates high transmissivity towards high yield of the aquifer units (Hasan 2018; Agbasi and Edet 2016; Ndatuwong and Yadav

2015). On the other hand, the low longitudinal conductance indicates that the aquifer unit is characterized by high permeability, hydraulic conductivity, and low clay volume (Hasan 2018; Agbasi and Edet 2016; Ndatuwong and Yadav 2015; Gowd 2004). In this study, the thematic maps of longitudinal conductance and transverse resistance were produced by Eqs. 1 and 2 using the spatial analysis tools in ArcGIS software. In the thematic map of Fig. 3a, the longitudinal conductance ranges from 0.061 to 5.795 mhos, and the low longitudinal conductance zone (< 0.8 mhos) indicates high potential groundwater. However, the low longitudinal conductance zone of

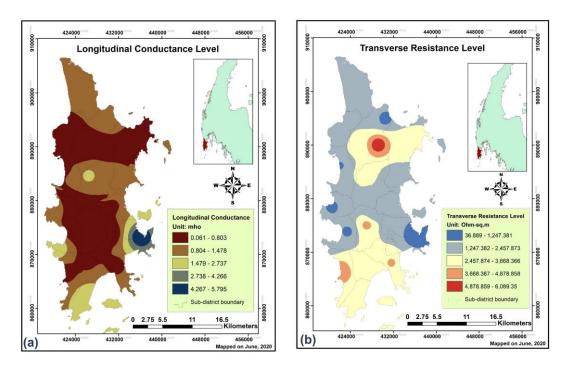


Fig 3. The base map of (a) longitudinal conductance and (b) transverse resistance

Table 3. Longitudinal conductance rating (protective capacity) of Aquifers (Oladapo and Akintorinwa 2007).

Longitudinal Conductance (mho)	Protective Capacity Rating
> 10	Excellent
5 to 10	Very good
0.7 to 4.9	Good
0.2 to 0.69	Moderate
0.1 to 0.19	Weak
<0.1	Poor

fewer than 0.1 mhos suggests an unprotected aquifer (contaminant risks), as shown in Table 3, and the high potential zone of the groundwater is mostly in the northern and the central parts of the study area. In the case of a transverse resistance thematic map (Fig. 3b), the high transverse resistance zone (> 5000 ohm-m²) indicates high potential of the groundwater locating in the center of the northern part in the study area. The thematic maps between longitudinal conductance and transverse resistance are complementary to each other, especially in the northern part of the study area. Consequently, the groundwater potential is not dependent on one parameter.

3.3 Groundwater potential delineation

The groundwater potential map of the study area was finally constructed based on thematic maps, i.e., longitudinal conductance and transverse resistance calculated from VES interpretation results, and the thematic maps of longitudinal conductance and transverse resistance were integrated by GIS software through weighted overlay method as a spatial analysis tool in ArcGIS 10.3 software. The integration was done based on a concept of good groundwater potential characteristics associated with low longitudinal conductance and high transverse resistance. Equal weight was assigned to the individual thematic maps and ranks were given based on the significance of groundwater. Finally, the groundwater potential was classified into the three categories 1) High, 2) Medium, and 3) Low, shown in Fig. 4. The groundwater potential map



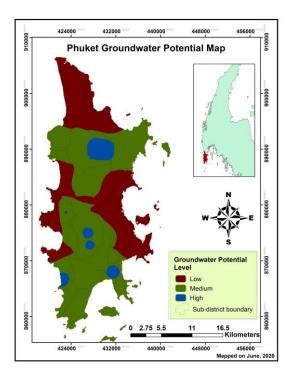


Fig 4. The map of groundwater potential in Phuket Island

some specific areas in the southern part, while poor groundwater potential is located in the top northern part and western and eastern flanks of the study area. Furthermore, moderate potential zone covers most of the study area. The map matches the groundwater potential map of Charoenpong et al. (2012), and shows a good agreement with that map, however, the map of this study identifies specifically the zone of groundwater potential, especially the high potential zones of groundwater, due to more parameters used in this study.

4. Conclusion

The geoelectrical data for estimating Dar Zarrouk parameters is an alternative approach for practical groundwater potential mapping and sustainable planning, as an alternative to the pumping test method that is expensive and laborious. The Dar Zarrouk parameters, i.e.

longitudinal conductance and transverse resistance, provide a good classification of different aquifer potential zones. The groundwater potential map in this study gives a broad idea about the favorable groundwater areas, and the map is very useful both for locating drilling sites and for obtaining an assessment of the general aquifer depth. The potential zones of the study area had moderate potential for 52.2% as the majority in the entire of the study area, while the high potential zones occupied approximately 5.5% of the study area, and are isolated and very limited. The flanks and top parts of the study area have a low potential, covering about 42.3% of the total area. Based on all the findings, this study emphasizes the value of geoelectrical data for groundwater development and utilization in the study area. The potential zones of this groundwater map were compatible with the potential map obtained by other methods (Chroenpong et al. 2012). Moreover, this study is a pioneering work that has carried out geoelectrical mapping of the groundwater potential, and the new findings of this study improve understanding of the groundwater characteristics in the study area. The research gap in this study is in validating the accuracy of the groundwater potential map, as the map should be validated by some field observations in order to match the potential zones classification into three categories on the map. However, this study encourages upcoming researchers by providing a groundwater platform to the local communities on groundwater issues and availability for development and management plans.

List of abbreviations

237

238

239

240

241

242

243

244

245

246

247

248

249

250

251

252

253

254

255

259

- VES: Vertical Electrical Sounding; GIS: Geo-informatic System; SPC: Specific Compacity;
- 257 GPS: Global Positioning System; RMS: Root-Mean-Square; WGS 1984: World Geodetic
- 258 System 1984; mbgl: Meter Below Ground Level.

Availability of data and materials

Not applicable

260

261

263

264

266

267

272

279

Competing interests

The authors declare that they have no competing interests.

Funding

- We would also like to address our sincere thanks to the Phuket Campus Research Fund, Prince of
- Songkla University [grant number X611196], for providing the budget for this research.

Authors' contributions

- AP initiated the methodology, review, writing, edition and final approval for submission. RM
- and SV conducted data acquisition, data inversion, formal analysis, interpretation and writing
- 269 draft of manuscript. SV prepared the manuscript based on the journal format. TS gave the
- 270 recommendations and editions for groundwater history information in the study area. All authors
- 271 read and approved the final manuscript.

Acknowledgements

- 273 We are grateful to the Department of Groundwater Resources, Thailand for providing the
- 274 groundwater data for this study and Assoc. Prof. Dr. Pham Huy Giao from the Asian Institute of
- 275 Technology (AIT) for his helpful suggestions. Furthermore, we would like to express special
- 276 thanks to the Faculty of Technology and Environment, Prince of Songkla University (PSU)
- 277 Phuket campus for their many suggestions and helpful support. Finally, we would like to thank
- the Publication Clinic run by the RDO of PSU for proofreading service.

References

- Advanced Geosciences, Inc. (AGI). Instruction Manual for Earthimager1D Version 2.4.2:
- Resistivity and IP Inversion Software; Advanced Geoscience Inc.: Austin, TX, USA, 2014.
- Advanced Geosciences, Inc. (AGI). Instruction Manual: Resistivity; Advanced Geoscience Inc.:
- 283 Austin, TX, USA, 2016.
- Agbasi OE, Edet SE (2016) Hydro-geoelectric study of aquifer potential in parts of Ikot Abasi
- local government area, Akwa Ibom state using Electrical Sesistivity Soundings. Int. J. of
- 286 Geol. & Earth Sci. 2:1-15.
- 287 Ali YH, Priju CP, Prasad NBN (2015) Delineation of Groundwater Potential Zones in Deep
- Midland Aquifers along Bharathapuzha River Basin, Kerala using Geophysical Methods.
- 289 Aquat. Procedia 4:1039 1046.
- 290 Amadi AN, Nwawulu CD, Unuevho CI, Okoye NO, Okunlola IA, Egharevba NA, Ako TA,
- Alkali YB (2011) Evaluation of the groundwater potential in Pompo Village, Gidan Kwano,
- 292 Minna using Vertical Electrical Resistivity Sounding. Br J Appl Sci Technol 1: 53-66.
- 293 Anbazhagan S, Jothibasu A (2016) Geoinformatics in groundwater potential mapping and
- sustainable development: a case study from southern India. HYDROLOG SCI J 61:1109-
- 295 1123. doi: 10.1080/02626667.2014.990966.
- 296 Charoenpong S, Suwanprasit C, Thongchumnum P (2012) Impacts of interpolation techniques
- on groundwater potential modeling using GIS in Phuket province, Thailand. In: The 33rd
- Asian Conference on Remote Sensing, Pattaya, Thailand.

- 299 Coker JO (2012) Vertical electrical sounding (VES) methods to delineate potential groundwater
- aquifers in Akobo area, Ibadan, South-western, Nigeria. J. Geol. Min. Res 4: 35-42. doi:
- 301 10.5897/JGMR11.014.
- Devi PD, Srinivasulu S, Raju KK (2001) Delineation of groundwater potential zones and
- electrical resistivity studies for groundwater exploration. Environ. Geol. 40:1252-1264. doi:
- 304 10.1007/s002540100304.
- Ezeh CC, Ugwu GZ (2010) Geoelectrical sounding for estimating groundwater potential in
- Nsukka L.G.A. Enugu State, Nigeria. INT J PHYS SCI 5: 415-420.
- 307 Giao PH, Weller A, Hien DH, Adisornsupawat K (2008) An approach to construct the
- weathering profile in a hilly granitic terrain based on electrical imaging. J APPL GEOPHYS
- 309 65: 30–38. doi:10.1016/j.jappgeo.2008.03.004.
- 310 Gowd SS (2004) Electrical resistivity surveys to delineate groundwater potential aquifers in
- 311 Peddavanka watershed, Anantapur District, Andhra Pradesh, India. Environ. Geol. 46:118–
- 312 131. doi: 10.1007/s00254-004-1023-2.
- 313 Gupta A, Babel MS, Das RK (2000) Assessment of groundwater potential with underground
- dam in Phuket Island of Thailand. In: 10th World Water Congress: Water, the Worlds Most
- 315 Important Resource, Melbourne, 731-738.
- Hasan M, Shang Y, Akhter G, Jin W (2018) Geophysical Assessment of Groundwater Potential:
- A Case Study from Mian Channu Area, Pakistan. Groundwater 56:783-796. doi:
- 318 10.1111/gwat.12617.

- Institute for Social and Environmental Transition-International (ISET); Thailand Environmental
- Institute (TEI); Vietnam National Institute for Science and Technology Policy and Strategy
- 321 Studies (VNISTPSS). Urban Vulnerability in Southeast Asia: Summary of Vulnerability
- assessments in Mekong-building Climate Resilience in Asian Cities (M-BRACE); ISET:
- Bangkok, Thailand, 2014.
- Kura NU, Ramli MF, Ibrahim S, Sulaiman WNA, Zaudi MA, Aris AZ (2014) A preliminary
- appraisal of the effect of pumping on seawater intrusion and upconing in a small tropical
- island using 2D resistivity technique. The Scientific World Journal 2014: 1-11.
- 327 doi:10.1155/2014/796425.
- Maury S, Balaji S (2014) Geoelectrical method in the investigation of groundwater resource and
- related issues in Ophiolite and Flysch formations of Port Blair, Andaman Island, India.
- Environ Earth Sci 71:183–199. doi: 10.1007/s12665-013-2423-y.
- Mailet R (1974) The Fundamental equations of electrical prospecting. Geophy. 12: 529 -556.
- Nagarajan M, Singh S (2009) Assessment of groundwater potential zones using GIS technique. J.
- Indian Soc. Remote Sens 37:69–77.
- Ndatuwong LG, Yadav GS (2015) Application of geo-electrical data to evaluate groundwater
- potential zone and assessment of overburden protective capacity in part of Sonebhadra
- district, Uttar Pradesh. Environ Earth Sci 73:3655–3664. doi: 10.1007/s12665-014-3649-z.
- Ojo JS, Olorunfemi MO, Akintorinwa OJ, Bayode S, Omosuyi GO, Akinluyi FO (2015) GIS
- Integrated Geomorphological, Geological and Geoelectrical Assessment of the Groundwater
- Potential of Akure Metropolis, Southwest Nigeria. J Earth Sci Geotech Eng 5:85-101.

- Oladapo MI, Akintorinwa OJ (2007) Hydrogeophysical study of Ogbese South Western Nigeria.
- Global Journal of Pure and Applied Science 13: 55-61.
- Puttiwongrak A, Kong SO, Vann S (2018) Groundwater Recharge Estimation in Kathu, Phuket
- using Groundwater Modelling. Geotechnical Engineering Journal of the SEAGS & AGSSEA
- 344 49:4-10.
- Puttiwongrak A, Vann S, Rattanakom R, Ruamkaew S (2019) Preliminary assessment of
- seawater intrusion on Phuket Island using groundwater data analysis and Geographic
- Information System (GIS) Techniques. Engineering Journal of Research and Development
- 348 30: 75-88.
- Tesfaldet YT, Puttiwongrak A, Arpornthip T (2019) Spatial and temporal variation of
- groundwater recharge in shallow aquifer in the Thepkasattri of Phuket, Thailand. J.
- 351 Groundw. Sci. Eng. 8:10-19. doi: 10.19637/j.cnki.2305-7068.2020.01.002.
- 352 Tesfaldet YT, Puttiwongrak A (2019) Seasonal groundwater recharge characterization using
- time-lapse electrical resistivity tomography in the Thepkasattri watershed on Phuket island,
- Thailand. Hydrology 6:1-15. doi:10.3390/hydrology6020036.
- Zaidi FK, Kassem OMK (2012) Use of electrical resistivity tomography in delineating zones of
- groundwater potential in arid regions: a case study from Diriyah region of Saudi Arabia.
- 357 Arab J Geosci 5:327–333. doi: 10.1007/s12517-010-0165-7.

Figures

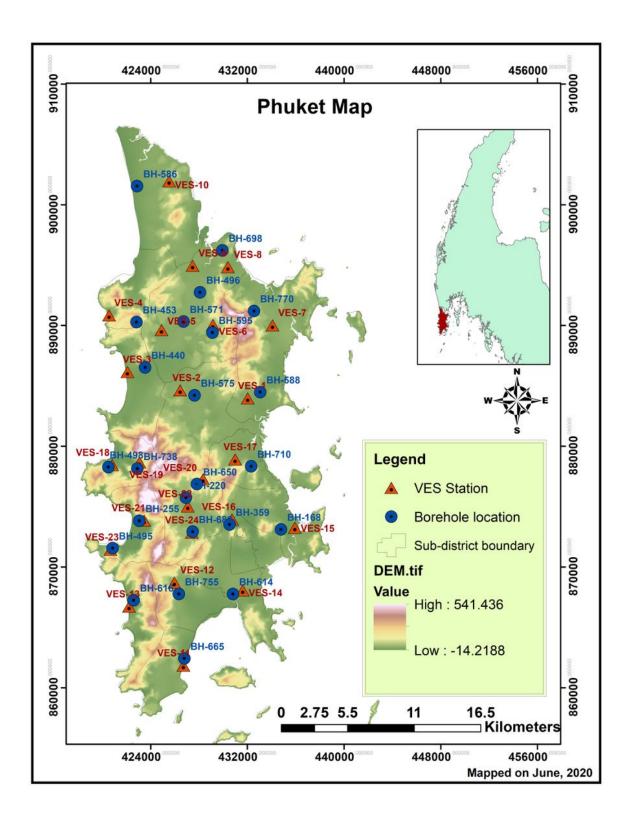


Figure 1

Map of study area showing VES stations and borehole locations

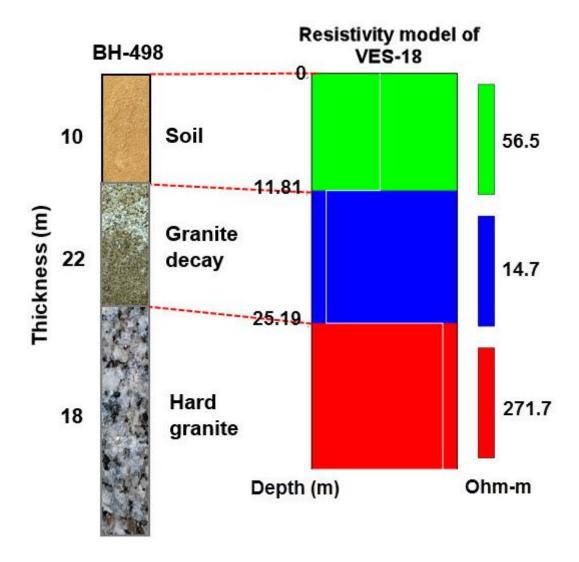
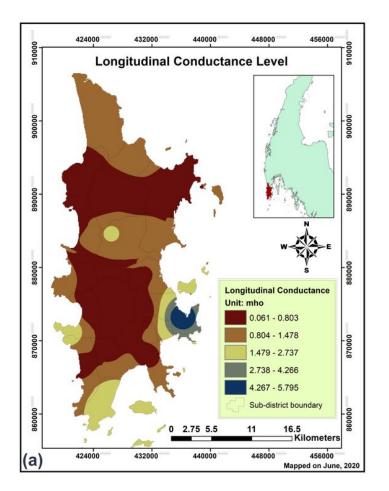


Figure 2

Correlation of layered resistivity model with borehole lithology



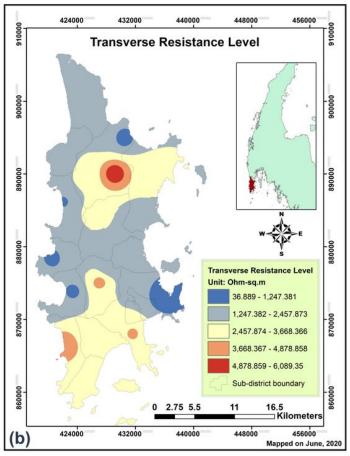


Figure 3

The base map of (a) longitudinal conductance and (b) transverse resistance

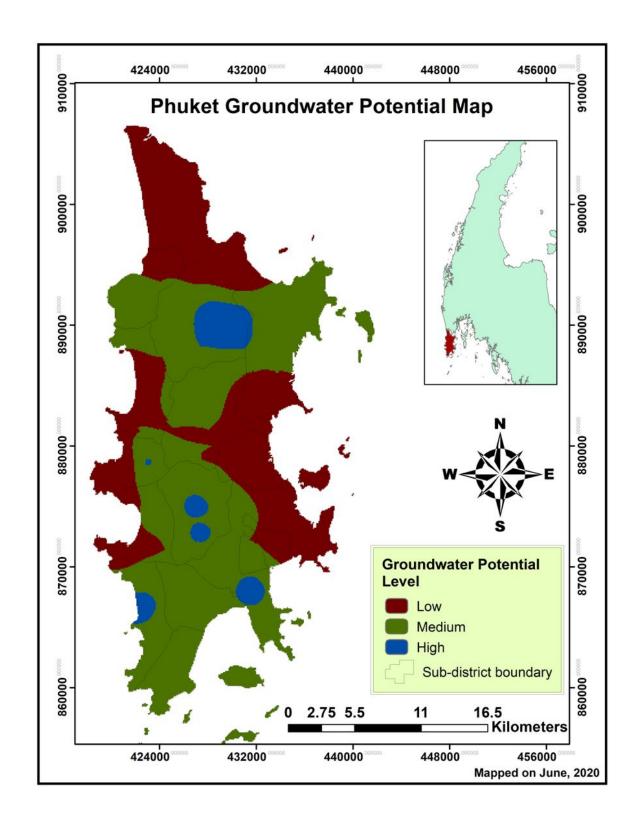


Figure 4The map of groundwater potential in Phuket Island